Translocations as a Tool for Restoring Populations of Bighorn Sheep

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Abstract

We analyzed factors that contributed to the success of 100 translocations of bighorn sheep within six western states between 1923 and 1997. We categorized the populations as unsuccessful (i.e., extirpated or remnant, <29 animals), moderately successful (30–99 animals), and successful (100–350 animals) by the end of the study period in 1997. Thirty of the translocated populations were unsuccessful ($n = 13$ were extirpated and $n = 17$ were remnant), 29 were moderately successful, and 41 were successful (21 ± 1.3 [SE] years of information per translocation). Translocations were less successful when domestic sheep were located within 6 km of the known bighorn sheep use areas (logistic regression, $p = 0.052$). Grazing of cattle on the same range also negatively influenced success ($p = 0.004$). Use of indigenous versus previously translocated source stocks increased success ($p = 0.084$). The translocation was twice as likely to be successful when indigenous herds were used as sources ($p = 0.043$), but mixing genetic stocks ($p = 0.381$) or later additional augmentations did not influence success ($p = 0.095$). Annual migrations by newly established translocated populations increased success ($p = 0.014$). We recommend translocations of founder groups of bighorn sheep from indigenous sources into large patches of habitat that promote movements and migrations, and with no domestic sheep present in the area.

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Introduction

Translocating animals into former habitats is an effective tool for the conservation of many species. However, translocations of large ungulates or carnivores can be expensive, time consuming, and logistically and politically challenging (Beck et al. 1994; Biggins & Thorne 1994; Wolf et al. 1996; Dunham 1997; Fritts et al. 1997).

Although guidelines exist to increase the success of translocation programs (Nielsen 1988; Stubbs 1988; Griffiths et al. 1989; World Conservation Union 1993; Gordon 1994; International Union for the Conservation of Nature and Natural Resources [IUCN] 1995; Wolf et al. 1996), the successes or failures of translocations are inadequately documented (Griffiths et al. 1989; Short et al. 1992), and the fate of some translocations is not monitored (Short et al. 1992). Translocation techniques are seldom tested, and many translocation projects are based partly or entirely on subjective beliefs (i.e., field savvy) that may or may not be correct (Hein 1997).

Only speculations exist on the former numbers (Seton 1929; Buechner 1960) of Rocky Mountain bighorn sheep *(Ovis canadensis canadensis)*, desert bighorn sheep (*O. c. nelsoni)*, and badlands bighorn sheep *(O. c. audobonii)* (but see Wehausen and Ramey [2000] who combine *O.c. audobonii* with *O.c. canadensis*). These subspecies of bighorn sheep were historically widespread and ubiquitous, inhabiting a large area of the alpine and foothills of the Rocky Mountains, the canyons and slickrock country of the Colorado Plateau, and the river breaks and rugged prairie badlands of the Dakotas (Cowan 1940; Buechner 1960; Bailey 1980; McCutcheon 1981). However, due to catastrophic declines in the late 1800s and early 1900s, the species was eliminated from the Dakotas, and nearly eliminated from Nevada, New Mexico, Utah, Washington, Oregon, and Colorado (Buechner 1960; Bailey 1980; Valdez & Krausman 1999). Most extant populations now exist as small, isolated groups occurring in a highly fragmented distribution. The Peninsular populations and the Sierra Nevada populations of California were recently listed as federally endangered populations (U.S. Federal Register 64:75 and 57:19837, respectively).

Efforts to restore populations of bighorn sheep have included extensive translocations (Bailey 1990; Jessup et al. 1995), water developments in desert environments (Leslie & Douglas 1979; Hanson 1980; Turner & Weaver 1980), prescribed burning to reduce tall cover on their ranges (Elliott 1978; Seip & Bunnell 1985; Hurley & Irwin 1986; Bentz & Woodard 1988), the feeding of treated bait to control parasites and pathogens (Schmidt et al. 1979), and the purchase or exchange of domestic sheep grazing allotments to relocate them from proposed bighorn sheep restoration sites (Desert Bighorn Council 1990). Even with these efforts, most restoration programs have failed to result in successes (Risenhoover et al. 1988). For example, only 53% of 87 translocated populations in nine western states were rated as successful (Leslie 1980). The purpose of our survey was to analyze factors contributing to the success or failure of all translocated populations of bighorn sheep in a six-state area of the western United States (U.S.) to provide better restoration procedures for the species. At the onset of our analysis, we made four predictions:

1. The presence of domestic sheep would be negatively correlated to the success of bighorn sheep translocations.
2. Translocations into desert environments should be more successful than nondeserts because fewer predators and fewer competitors exist in deserts (Dunham 1997).
3. Higher genetic variability would promote the success of translocations (Bailey 1990). Specifically, we predicted higher success with larger founder group sizes (Griffiths et al. 1989) because more of the source herd's total genetic heterozygosity would be captured in a larger founder group and during any augmentations (for the same reason). A larger number of source stock mixed in the founder group should also increase heterozygosity, the genetic mixing hypothesis of Bailey (1990), and use of indigenous versus dilution (i.e., previously translocated) stocks (Bailey 1990) because indigenous populations generally have higher genetic heterozygosity than translocated populations (Fitzsimmons et al. 1997). Also, gene flow between translocated populations or any nearby resident populations should increase heterozygosity.
4. Migratory translocated populations would be more successful than sedentary populations (Risenhoover et al. 1988).

Methods

Definitions

We defined a translocation as a release of bighorn sheep into an area with no other bighorns present. If multiple releases occurred within a one-year period, we considered them part of the initial translocation. Any releases conducted greater than one year apart were defined as augmentations. Successful populations were defined as all populations numbering greater than or equal to 100 animals in 1997. Populations of modest success were defined as populations numbering 30–99 in 1997. Unsuccessful translocations were defined as any translocated population that was extirpated or was a remnant population (1–29 animals) in 1997 and with low possibility of ever recovering (Thorne et al. 1985; Krausman & Leopold 1986; Berger 1990; Krausman et al. 1993; Goodson 1994). These categories generally follow the definition of a minimum viable population of 100 $\pm$ 20 bighorn sheep adopted by the U.S. Department of the Interior, Bureau of Land Management (1996) supported by Berger (1990): high persistence of populations greater than or equal to 100 for at least 5 decades, but modest persistence for populations of 50–99, and low persistence for populations numbering less than or equal to 49. We relaxed Berger's criteria for a remnant population $\leqslant$29 based on data presented by Krausman et al. (1993), Goodson (1994), and Wehausen (1999) that a few populations of 30–50 might persist and later recover.

The Survey

The survey was mailed to state and federal managers in Colorado, Montana, North Dakota, South Dakota, Wyoming, and Utah. We asked 36 simple questions requiring only numbers or yes/no answers. These included: the year of translocation, number of releases, number of animals released, sex, age, and estimated maximum potential N_e (i.e., genetic effective number) of the founder group (N_e here defined as potential breeding-aged animals), release method (e.g., hard = immediate release or soft = animals held in the field in pens for a period prior to release), any augmentations, any known contact with domestic sheep, distance to domestic sheep, presence/absence of cattle grazing on the same range, population trend, annual census estimates, any population estimation techniques and corrections, range expansions, habitat condition and trend, occurrence of large fires, whether or not the area was historic range for native bighorn sheep, any documented outbreak(s) of disease, hunting, and distance to the nearest other wild bighorn sheep population (either indigenous or previously translocated). We also asked managers if the translocated population was: (1) non-migratory and resident year-round on the same range; (2) partially migratory (i.e., 25–75% of the population migrated each year); or (3) migratory (i.e., >76% of the population migrated each year). We asked the managers the total distance (to the nearest whole km) the animals migrated. In addition to the mailed survey, we augmented our information with telephone calls to the managers, and by reviewing additional population and range studies of the translocated herds provided in government reports (Steel et al. 1987; Coates & Schemnitz 1988; Smith & Butler 1988), two graduate theses (Barmore 1962; Fairaizl

1978), and nine publications (Rutherford 1972; Cook et al. 1980; Ravey & Schmidt 1981; Kopec 1982; Creeden & Schmidt 1983; Stevens & Hanson 1986; Irby & Andryk 1987; Smith et al. 1988; Creeden & Graham 1997).

Population Estimates and Rates of Population Growth

The translocated populations of bighorn sheep we used in this analysis included only populations where good population estimates were available and mortality, range expansion, and general health of the animals was monitored. We excluded from all further analyses 33 populations that had insufficient census information or survey responses. Of 100 translocations we used, 82 populations had 489 animals marked or radio-collared ($n = 299$) while 18 populations had no markers. Corrected population estimates using mark-resight (Neal et al. 1993) or a sightability model (Bodie et al. 1995) for helicopter surveys or harvest models (Bartholow 1999) were provided for 68 translocated populations; no corrections were provided for 32 translocated populations. For those 32 uncorrected counts, we multiplied the total raw count by 200 ± 18 (CI) % based on average visibility corrections obtained from 5 populations occurring in a variety of habitats (Neal et al. 1993; Bodie et al. 1995; Kissell 1996).

We calculated population growth rates (r) from the annual population change averaged over the period of information (r = population size [N] at time [t]/N [t – 1]). We deleted translocations from the original survey ($n = 105$) that did not occur in historic habitat ($n = 2$) from analysis. Only three releases were soft releases, defined as animals held in pens at the site for months, so we deleted them also, leaving $n = 100$ populations used in this study.

Univariate Analysis

We conducted univariate logistic analysis because some variables were not answered by all respondents. We used Systat version 7.0 for all univariate statistical analyses. We used Akaike Information Criteria (AIC) (Akaike 1973, 1985) to rank the effect of the independent variables on success of translocations. For categorical independent variables, we used Fisher's exact tests (Berry & Mielke 1987, 1988; Mielke & Berry 1992) to compare the differences between successful and unsuccessful translocations. For continuous variables we used t tests to compare the means for successful and unsuccessful translocations. We used Levene's test to check for the equality of variance.

Results

Thirty of 100 bighorn sheep translocations were unsuccessful. Thirteen translocated populations were extirpated and another 17 were remnant (<29 animals) at the end of the study period. Twenty-nine of the translocations were of only modest success, and only 41 were completely successful. Of these 70 populations, 43 increased steadily following initial translocation; 11 increased initially but then declined; 15 increased, declined, but then recovered; and one population fluctuated widely. Years of information since the initial translocation to the present, or the year of extirpation, averaged 21 ± 1.33 (SE) years and ranged from one year for an extirpation to 74 years of information. Eleven of the translocations were desert bighorn subspecies sheep from the Colorado Plateau of Utah, 81 were Rocky Mountain bighorn, and 8 were California bighorn sheep (*O. c. californiana*).

Bighorn sheep released into the Colorado Plateau increased at a higher rate ($r = 0.13$) than did animals released into Rocky Mountain habitats ($r = 0.02$), or those released into the prairie badlands habitats ($r = 0.03$) of South and North Dakota (Kruskal–Wallis test, $p = 0.018$). Contact with domestic sheep and distance to domestic sheep were the most significant variables (i.e., had the lowest AIC values). Success of translocated populations was negatively correlated with the presence of domestic sheep on their range (logistic regression, $p = 0.052$, AIC = 70.5, Fig. 1). Translocations having known contact with domestic sheep were more likely to fail (50% unsuccessful) than if they did not have contact (25% unsuccessful) (Fisher's exact test, $p = 0.0682$, Fig. 1). Unsuccessful translocated populations were located closer ($\bar{x} = 6 \pm 2$ km) to domestic sheep than were modestly successful or successful translocations ($\bar{x} = 20$ km) (Fig. 1). Grazing of domestic cattle on the range was also negatively correlated to rate of increase (r) of translocated populations of bighorn sheep ($p = 0.004$). Twenty-seven percent fewer translocations were successful when cattle grazed the area. The presence of domestic sheep had a greater negative impact on success than did the presence of cattle.

Migratory tendency and the annual distance migrated of the translocated population was associated with success (based on the logistic regression and AIC values (Table 1). Only 65% of non-migratory populations were successful, but 81% of partially migratory and 100% of fully migratory populations were successful (Table 1). Hunting of bighorn sheep was also positively associated with success of the translocation (Fisher's exact test, $p = 0.001$).

The genetic diversity hypotheses were only partially supported. Success rate was about double (successful: 48%; modest: 25%; unsuccessful: 27%) when an indigenous population was used as a source (with generally higher genetic heterozygosity [Fitzsimmons et al. 1997] versus a previously translocated herd [successful: 24%; modest: 38%; unsuccessful: 38%]) (Fisher's exact test, $p = 0.043$). Larger founder sizes also increased the suc-

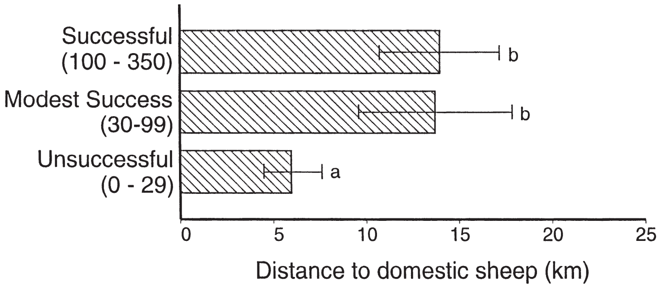

Figure 1. Success of bighorn sheep translocations in relation to distance to the nearest domestic sheep, western United States, 1923–1997. Different letters denote statistical significance ($p < 0.05$).

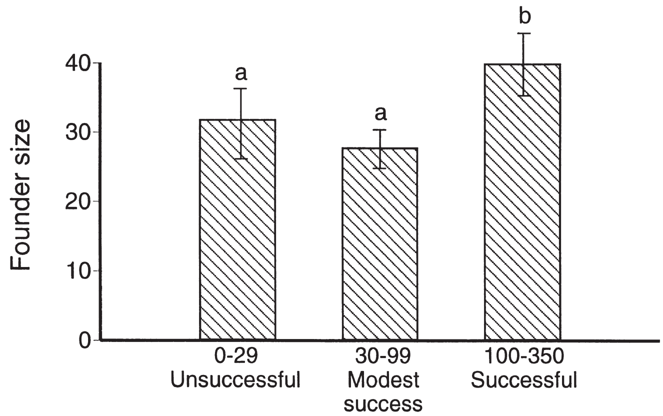

Figure 2. Founder size and success of translocations of bighorn sheep in the western United States, 1923–1997. Different letters denote statistical significance ($p < 0.05$).

cess of translocations ($p = 0.060$). The average size of founder groups for successful translocations was 41.3 ± 4.3 animals, but the average size for less successful translocations was 29.5 ± 3.5 (Fig. 2). However, gene flow between populations ($p = 0.623$) and use of single versus multiple source herds ($p = 0.293$) did not statistically significantly influence success. The effect of later augmentations (which would tend to increase genetic heterozygosity of the founding group) was equivocal ($p = 0.095$).

Discussion

Bighorn sheep may die from disease following exposure to domestic sheep. Most, or all, bighorn sheep die (with no ill effects to the domestic sheep) in penned experiments with domestic sheep (Foreyt 1989; Callan et al. 1991). In wild situations, 28 instances of a die-off or decline in free-ranging bighorn sheep herds immediately following contact with domestic sheep have been reported (Jessup 1985; Blaisdell 1982; Foreyt & Jessup 1982; Onderka & Wishart 1984; Clark et al. 1985; Sandoval 1988; McCarty & Bailey 1994). But the cause-and-effect relationship to domestic sheep is not perfect, since stress (Spraker et al. 1984), overpopulation (Wishart et al. 1980; Festa-Bianchet 1988), a new immigrating wild bighorn (Onderka & Wishart 1984), or spontaneous outbreaks of Pasteurellosis (Miller et al. 1991) have also caused die-offs in bighorn sheep with no known, or immediately prior, contact with domestic sheep. The typical vector for transmission is a wild bighorn male that may visit a flock of domestic ewes in estrus and then return to other wild bighorns. Bighorn males may travel long distances between mountain ranges during rut (Ough & DeVos 1986; Bleich et al. 1996) increasing the chance of encountering a flock of domestic sheep. The only prior attempt to look at the status of large numbers of bighorn sheep populations showed a non-statistical, but negative, relationship between free-ranging bighorn sheep and domestic sheep (Goodson 1982).

Several authors recommend avoiding direct, physical contact of any kind between domestic sheep and bighorn sheep (Jessup 1985; Blaisdell 1982; Onderka et al. 1988; Spraker & Adrian 1990). Resource management agency guidelines recommend distances of 13.5 km (Desert Bighorn Council 1990) or 16 km (U.S. Department of the Interior, Bureau of Land Management 1992) to separate any domestic sheep and free-ranging bighorn sheep; a guideline that is also generally supported by our analysis. Jessup et al. (1995) recommended testing the source stock of wild bighorn sheep for active pathogens before translocating them to a new area. Real (1996) stated that diseases and their pathogenic effects on wildlife must be incorporated into any ecosystem restoration management strategy.

The biological evidence for the negative association with domestic cattle is equivocal. Bighorn sheep may prefer not to graze on areas already heavily grazed by cattle (Spraker & Adrian 1990). Bighorn sheep were reported to actively avoid cattle in some situations (Irvine 1969; Wilson 1969; Spraker & Adrian 1990) and diet overlaps were large between the two species in mountainous habitats (King & Workman 1984). But other

Table 1. Logistic analysis on success or failure of 100 bighorn sheep translocations in the western United States. AIC = Akaike Information Criteria.

Variable	*P*	*−2Log Likelihood*	*AIC*
Contact with domestic sheep	0.052	66.556	70.556
Distance to domestic sheep	0.021	77.912	79.912
Migratory tendency	0.014	75.198	81.198
Distance migrated	0.04	88.256	90.256
Presence of livestock	0.019	105.334	109.334

studies did not document active avoidance of cattle by bighorns (Dodd & Brady 1986), and habitat overlap was minimal. Habitat overlap between the two species was less than 10% because cattle prefer slopes of less than 30%, or the lower parts of slopes less than 50%, while bighorn sheep prefer slopes greater than 70% (Tilton & Willard 1982; Cunningham & Ohmart 1986; Dodd & Brady 1986; King & Workman 1984). Also, diet overlap between the two species in desert environments was minimal (Dodd & Brady 1986). But several authors report concern that bighorn sheep might contract several pathogens from domestic cattle (Jessup 1985; Spraker & Adrian 1990). Several pathogens such as parainfluenza type 3 (PI-3), bovine respiratory *syncytail* virus, and bluetongue could be transmitted from cattle to bighorn sheep at sites of contact such as a shared water source (Jessup 1985; Spraker & Adrian 1990). The presence of domestic cattle was implicated in the decline of two bighorn herds in California (DeForge & Scott 1982; DeForge et al. 1981). *P. haemolytica* biotype A from cattle directly inoculated into eight captive bighorn sheep killed five of the animals from fatal septicemia and fibrinous bronchopneumonia (Onderka et al. 1988). Several other authors, however, reported no evidence for transmission of pathogens from free-ranging domestic cattle to free-ranging bighorn sheep (Mouton et al. 1991; McCarty & Bailey 1994). We recommend further research into potential conflicts between cattle and wild bighorns.

Migration of bighorn sheep was associated with success of translocations, as we predicted. Most, or all, alpine dwelling, Rocky Mountain, indigenous populations of bighorn sheep migrate distances of 10–64 km annually (Smith 1954; Geist 1971; Demarchi & Mitchell 1973). Many indigenous desert populations, although not as clearly migratory, also use seasonal ranges separated by a few km to 30 km annually (Ough & DeVos 1986; Bleich et al. 1990). The absence of migration in Rocky Mountain habitats appears to be a recent consequence of human-caused habitat fragmentation and habitat alterations, including forest succession due to fire suppression which limits use of habitats (Risenhoover & Bailey 1985; Wakelyn 1987). Isolation and declining population status serve to reduce migrations and dispersal in many populations (Lenarz 1979; Bailey 1980; Risenhoover et al. 1988). Confinement year-round on the same range may increase transmission rates for lungworms (*Protostrongylus* spp.), increase predator efficiency, and result in higher use of the available forage (Risenhoover et al. 1988). Bailey (1980) suspected that bighorn sheep were more mobile and migrated and dispersed more extensively before the arrival of Europeans and their developments. We recommend management that will facilitate the movements of bighorn sheep including: (1) translocating bighorns into large blocks of habitat with a variety of potential seasonal habitats; (2) translocating into areas with the potential for greater than one subpopulation; (3) burning or easements to eliminate tall vegetation and encourage the use of movement corridors; and (4) conducting additional translocations to expand the ranges of sedentary populations.

Our finding that translocations of bighorn sheep into cool desert environments of the Colorado Plateau were more successful than Rocky Mountain or prairie habitats was predicted by Dunham (1997), who felt that deserts supported fewer predators and competitors, and that desert ungulates were more varied and flexible in their diets and habitat use. Several authors report desert bighorn sheep have more variable and flexible diets than Rocky Mountain populations, eating many desert shrubs, forbs, and graminoids (Krausman et al. 1989; Miller & Gaud 1989; McCarty & Bailey 1994). Desert bighorn sheep are apparently well adapted to life in the Colorado Plateau desert, being smaller, with longer extremities, lighter color, and a sleek, glossy coat that reflects light (McCutcheon 1981). Desert bighorn sheep ewes also typically breed one year earlier than the Rocky Mountain bighorn (McCutcheon 1981; Berger 1982), a factor that can contribute to higher population growth rates during favorable periods in the desert. But these findings are in stark contrast to Bailey (1980), who felt the desert bighorn sheep subspecies was maladapted to modern conditions. The high success of desert translocations in our study may be a result of the translocations into the cool deserts of the Colorado Plateau, a vast inaccessible area that is extremely rugged, containing six large national parks and monuments, and little disturbed by any major human developments. There is also a relative lack of tall vegetation to interfere with movements, few domestic sheep or cattle in this region, relatively few breaks in escape terrain, and few highway barriers to movements.

Greater success when using indigenous founding sources may be related to greater genetic heterozygosity than using dilution (translocated) populations (Fitzsimmons et al. 1997). Griffiths et al. (1989) and Wolf et al. (1996) also found larger founder sizes promoted success of translocations. National Park Service (NPS) policy stresses genetic conservation and urges that only subspecies and stocks as closely related as possible to the extirpated population should be used in a translocation (U.S. Department of the Interior, National Park Service 1988; U.S. Department of the Interior, National Park Service 1991; Ramey 1993). Also, augmentations of existing, native populations should only be practiced when genetic variation is limited, the diminished population is threatened with extirpation, and the diminished status is the result of human activities (U.S. Department of the Interior, National Park Service 1991). Greig (1979) argued that locally adapted genotypes should not unnecessarily be mixed. In addition, mixing the sources of bighorn sheep carries the risk of introducing novel pathogens from one herd to the next, and possibly introducing pathogens to herds that are more susceptible (Sandoval 1988; Miller et al. 1991). In support of our conclusion, Bailey (1990) also reported that mixing source stocks increased success of translocations and Fitzsimmons et al. (1997) reported the practice increased genetic diversity.

Management Recommendations

Our strongest recommendation is to translocate bighorn sheep only to areas without domestic sheep less than 20 km away, or by using double fencing, herding practices, or barriers that will separate the two species. We recommend only indigenous herds be used as source stocks, and that founder size be greater than or equal to 41 animals, although some translocations that did not meet these criteria were successful. We recommend migration of the released group be encouraged through clearing of movement barriers and selecting large habitat patches for releases that possess potential for migratory movements. A greater tendency to wander might in some cases eventually lead to increased likelihood of contact with domestic sheep, presenting managers with a potential dilemma in some restoration areas. Managers should consider mixing source stocks since genetic diversity and success of translocations is increased, but we withhold any recommendation for routine mixing of source stocks until more research is conducted. In some cases the mixing might introduce a novel pathogen to one of the groups.

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